

COMPARATIVE MODELING ON SURFACE ROUGHNESS FOR ROLLER BURNISHING PROCESS, USING FUZZY LOGIC.

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ABSTRACT

Roller burnishing is one of the surface finishing processes without removing of a material, where a roller rolls over the machined surface under high pressure and flattens, the roughness peaks into valley. It will improve surface finish, as well as enforces favorable compressive residual stresses and raises hardness in functional surfaces. Aluminium alloys find attractive alternate for high strength applications.

In this experimental work, burnishing operation is carried out on various Aluminium alloys, such as Al 2014 and Al 6063 using different burnishing parameters, such as cutting speed, feed, no of passes and depth of cut using burnishing tool. Through this experimental work, parameter that affects the surface roughness and surface hardness, on Al 2014 and 6063 material was identified and its influence on these responses was discussed.

Also, the studies include the application one of the machine learning techniques is fuzzy logic, in the aspects of modeling and optimization of various process parameters applied, with roller burnishing process. This would give the comprehensive idea on choosing an optimum burnishing condition.

KEYWORDS: Aluminium 2014, Aluminium 6063, Fuzzy Logic, Hardness, Optimization, Roller Burnishing, Residual Stress & Surface Finish

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INTRODUCTION

Surface Finishing Process

The surface environment of an engineered surface is generally written off, as in terms of surface finish, condition of residual stress, microstructure and hardness. Generally, fine surface finish, high compressive residual stress, and high hardness of the surface layer protract the fatigue life of the components. During 1980's, hard turning technology development made it possible, to replace at least some rough grinding with single-point cutting processes. However, the applications of hard turning as a finishing process are limited by tool wear. To broaden the capability of hard turning as a finishing process, it is practical to provide necessary surface modifications (i.e. improving surface finish and converting tensile residual stresses to compressive). Therefore, a hard roller burnishing would be best suitable since the burnishing tool can be readily installed on the same CNC machine setting.

Surface Parameters

Surface parameters (roughness, hardness, residual stress) are crucial factors to decide fatigue life of materials. Poor surface finish lead moisture content on surface region of material and import tensile residual stress.

These two factors are very harmful for fatigue behavior of materials. Generally material removal process such as machining, grinding, etc. lead poor surface finish. After that, the material goes under super finishing process. Nowadays burnishing process becomes more popular as a finishing process.

Surface Roughness and Hardness

Surface finish affects wear resistance, load bearing capacity, and corrosion resistance of the surface of the component. During burnishing process, the tool compresses the outer surface layer by the polished hardened tool (ball or roller) so that it reduces the surface roughness. Other parameter like surface hardness is inversely proportional to the surface roughness. The reduction in surface roughness increases the surface hardness simultaneously.

Residual stress is that which remains in a body that is stationary and at equilibrium with its surroundings. It can be very detrimental to the performance of a material or the life of a component. Alternatively, beneficial residual stresses introduced deliberately. Residual stresses are more difficult to predict than the in-service stresses on which they superimpose. For this reason, it is important to have reliable methods for the measurement of these stresses and to understand the level of information about this stress.

With modern analytical and computational techniques, it is often possible to estimate the stresses to which a component subjected in service. This in itself is not sufficient for the reliable prediction of component performance. Indeed, in many cases where unexpected failure has occurred, this has been due to the presence of residual stresses, which have combined with the service stresses to shorten component life seriously. On the other hand, compressive stresses sometimes introduced deliberately, as in shot peening, burnishing, which is used to improve fatigue resistance. Furthermore, in natural or artificial multiphase materials, residual stresses can arise from differences in thermal expansivity, yield stress, or stiffness. Considerable effort is, currently being devoted to the development of a basic framework within which, residual stresses can be incorporated into design in aerospace, nuclear, and other critical engineering industries.

Burnishing process is better to impart the compressive residual stress than other process. The Surface compressive stresses to enhance the fatigue life could also produce by shot peening and laser shock peening. However, in the processes thermal relaxation was found, result in loss of the surface-layer compressive stresses with consequent shortening of component life. Hence, what is needed is means of imparting thermally stable surface compressive stresses. Burnishing is a process, which can impart thermally stable surface compressive stresses.

LITERATURE SURVEY

The literature review indicates that earlier investigations concentrated on the effect of the ball burnishing process dealing mostly with surface finish and surface hardness with little focus on optimization of the burnishing parameters.

El-Tayeb et al. [1], low done the process on Influence of roller burnishing contact width and burnishing orientation, on surface quality and tribo logical behavior of Aluminium 6061. Sundararajan [2] investigated about Optimization of roller burnishing process, for aluminium using taguchi technique. Luca et al., Neagu-Ventzel, Marinescu [3] determined of Effects of working parameters on surface finish in ball-burnishing of hardened steels. Hassan [4] finds the effects of ball- and roller-burnishing, on the surface roughness and hardness of some non-ferrous metals.

Yeldose and Ramamoorthy [5], examined the use of the roller burnishing process to give a good surface integrity for steel EN24 work material. Luo and Liu [6], investigated the influence of the main burnishing parameters on the surface roughness and the hardness of two different non-ferrous metals. Nemat and Lyons [7], performed the experiment to study the effects of burnishing speed, feed, ball diameter, burnishing force and the number of passes on the quality of the work surface produced and its wearing characteristics. Bonzid et al. [8], established the effects of four ball burnishing parameters: depth of penetration, feed, ball material and lubricant on the surface roughness of AISI 1042 steel specimens. An analytical model has been defined to determine the relation between surface roughness and feed. Luo and Liu [9], presented a three-dimensional burnishing force model, based on elastic-plastic contact mechanics and elastic-plastic impact mechanics. From this burnishing force model, a more ideal burnished surface can be obtained by deliberately controlling certain parameters. Adal and Ayman [10], studied the effect of initial burnishing parameters on non-ferrous components. The results show that most of the parameters like ball diameter, initial surface hardness, roughness and the use of the different lubricants have significant effect on the burnishing process. Esme et al. [11], developed an artificial neural network model for the prediction surface roughness of AA 7075 aluminum alloy in ball burnishing process. Korzynski [12], investigated the relation between burnishing force and surface roughness for smoothing burnishing with a spherical tool. Seemikeri et al. [13], focused on the surface roughness, micro hardness, surface integrity and fatigue life aspects of AISI 1045 work material using full factorial design of experiments. Hassan et al. [14] examined the effect of the measure parameters (burnishing force and number of passes) on the surface roughness using RSM. They established a mathematical model to correlate burnishing force and number of passes with surface finish. El-Tayeb et al. [15] investigated the effect of ball burnishing parameters such as speed, force, ball diameter and orientation on the surface qualities and tribological properties of burnished surfaces of aluminium 6061, for different burnishing orientation. Rao et al. [16] studied the effect of ball diameter, speed, feed and lubricant on surface hardness of high strength low alloy steel dual-phase steels. They determined the optimal burnishing parameters on dual-phase steels. Loh et al. [17] investigated the effects of various parameters on the surface roughness of aluminium alloy. They discussed optimum burnishing parameters and conditions. El-Khabeery and El-Axir [18] examined the use of the roller burnishing process to improve surface integrity for 6061 aluminium alloy, using a vertical milling machine. To explore the optimum combination of burnishing parameters, the experiments were designed based on RSM with CCD. El-Taweel and El-Axir [19], studied the analysis and optimization of the ball burnishing process, using Taguchi method. They examined the influence of some burnishing parameters such as speed, feed, force and number of passes on the surface roughness, surface micro-hardness, the improvement ratio of surface roughness and the improvement ratio of surface micro-hardness and determined the optimal combination level of the ball burnishing parameters. El-Axir et al. [20] studied on the surface finishing of 2014 aluminium alloy, by ball burnishing process. The experiments were designed on the basis of RSM with CCD. They developed response models using RSM. El-Taweel and Ebied [21] proposed a novel finishing process, which integrates the merits of electromechanical smoothing and roller burnishing, for minimizing the roundness error and increasing surface micro-hardness of cylindrical parts. They explored the optimum combinations of the burnishing parameters using RSM. Yan et al. [22] investigated the feasibility and optimization of a rotary electrical discharge machining with ball burnishing for inspecting the machinability of Al composite material using the Taguchi method. Shiou and Hsu [23] determined the optimal flat surface ball burnishing parameters for the stainless mould steel, after having executed the Taguchi's L9 experiments, analysis of variance, the full factorial experiments and confirmation experiments on the machining centre. Shiou and Cheng [24], studied the effect of ball burnishing parameters on surface finish of a free form surface plastic

injection mould on a machining centre. For burnishing parameters namely the ball material, burnishing speed, feed and force were selected as the experimental factors of Taguchi's design of experiments to determine the optimal burnishing parameters, which have a dominant influence on surface roughness. Shiou and Chen [25] determined the optimal plane ball-burnishing parameters for plastic injection molding steel PDS 5 on a machining centre, utilizing the Taguchi's orthogonal array method. Basak and Goktas [26], discussed the burnishing parameters which affect to surface roughness and surface hardness on Al 7075 materials. They developed a fuzzy logic model and obtained the best parameters for the burnishing process. In the present work, desirability function approach together with response surface methodology has been used to minimize surface roughness in ball burnishing process. A quadratic model was developed to predict the effect of the ball burnishing parameters on surface roughness by using multiple regression analysis. Validation experiments were conducted on random set of experiment under optimal conditions.

Most of the work on burnishing that has already been published was concerned with the effect of the burnishing process on surface roughness and surface hardness [27]. The changes in the surface characteristics due to burnishing will cause improvements in surface hardness, surface roughness, wear resistance, fatigue and corrosion resistance as claimed by many authors [28-31] which in turn improve corrosion resistance, wear resistance [32-38], tensile strength, larger maximum residual stress in compression [39-41]

EXPERIMENTAL DETAILS

Schematic Illustration of Burnishing Operation

The figure 1 shows, the roller burnishing process. Roller burnishing tool is used and burnishing force is given vertically.

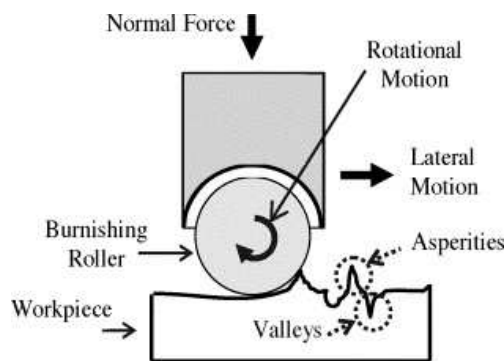


Figure 1: Schematic Illustration of Burnishing Mechanism

Burnishing 'cold-works' the metal of a machined part. Tool marks are rolled out. Grain structure is condensed and refined, and compacted surface is smoother, harder and longer wearing than ground or honed surfaces. Rolling action greatly reduces surface porosity, pits and scratches which could hold reactive surfaces or contaminants. As a result the corrosion resistance of burnished surface is higher than the open surfaces produced by grinding or honing. Depending on the type of material being burnished surface hardness can be increased by as much as 10-RC. This increase often eliminates the need for heat treating or surface treatment as a means of improving wear resistance. Due to plastic deformation in the roller burnishing operation, residual compressive stresses are induced in the surface of the part. This compressive stresses greatly increase the strength properties and fatigue life of the part, because any forces on the part must overcome these residual stresses, as well as the tensile strength of the material, before fatigue conditions occur. Power requirements for burnishing are very low due to the small amount of torque generated. Work holding problems are

therefore considerably simplified when designing fixtures and machine setups to be employed in surface finishing with this Type tool.

Work Piece Material

In this project work, Aluminium 2014 with chemical composition 0.74% Mg, 0.53% Si, 0.013% Mn, 0.214% Fe, 0.004% Cu, 0.003% Zn, 0.01% Ti, 0.002%, Cr was used as work piece material. Aluminium 2014 was selected because of its wide range of applications in the industry such as aircraft fittings, truck wheels, brake disks, hinge pins, couplings, brake pistons and hydraulic pistons. The figure2 shows the aluminium 2014 work piece. The work piece is initially of 300mm length, 28mm diameter. The work piece is divided into fifteen divisions of 20mm length and tested for same condition under different passes.



Figure 2: Aluminium 2014 & 6063 Work Piece

Also, Aluminium 6063 with chemical composition 0.45 – 0.9 Mg, 0.20 – 0.6 Si, 0.10 Mn, 0.35 Fe, 0.10 Cu, and 0.10 Cr was used as work piece material. Aluminium 2063 was selected, because of its wide range of applications in the industry such as Architectural and building products, Door and window frames, Electrical components and conduit, Railings and furniture, Pipe and tube for irrigation systems, Heat sinks. The work piece is initially of 300mm length, 30mm diameter. The work piece is divided into fifteen divisions of 20mm length and tested for same condition under different passes.

Burnishing Tool

A burnishing tool with interchangeable springs are designed and fabricated for the experimental tests. The tool consists of a shank which must be firmly gripped in the tool holder of the vertical machining centre. An interchangeable spring is designed to give a load up to 1430N. There is a dowel pin used to indicate the deflection of the spring thereby calculating the force applied on the work piece. The tool head consist of a High speed steel roller of 4mm contact width which flows through the work piece causing burnishing effect. The schematic drawing of the tool is shown in figure3.



Figure 3: Roller Burnishing Tool

Table1. Tungsten Carbide Tool Elements

Element Kg/m ³	WC	Ni	Co	Density
%	94	3	3	8920

Machining Process

The experiments were performed on an industrial type of CNC lathe. The burnishing tool was mounted on tool holder of the CNC. The work piece was clamped by the three jaw chuck and tailstock Centre of the machine. No coolant was used during burnishing. Photography of the burnishing process is shown in Figure4.

**Figure 4: Photographic View of the Burnishing Process****Figure 5: Photographic View of Al 2014 Machined Part**

Burnishing Conditions

In this work external moving single roller burnishing tests were performed. All of the burnishing tests were performed in CNC machine. Three burnishing parameters were chosen, namely burnishing speed (N), Burnishing feed (f), depth of penetration (d).

Table 2: Burnishing Condition

Parameter	Unit	Level of factors		
		1	2	3
Burnishing speed (v)	Rpm	100	125	150
Burnishing feed (f)	mm / rev	0.2	0.4	0.6
Depth of cut (d)	mm	0.5	1	1.5

Since dry burnishing conditions produced poor surface finish it was decided to apply suitable soluble oil during all tests. It was emulsion-type soluble oil mixed with water. In addition, a constant single roller diameter of 48 mm was used throughout this investigation.

TESTING AND ANALYSIS

Measurement of Surface Roughness Values

A repetitive or random deviation from the nominal surface which forms the pattern of the surface is known as surface texture. It includes roughness, waviness, flaws, etc. Waviness is due to the geometric errors of machine tool and

varying stiffness of the machine tool. Roughness is due to the inherent kinematic differences of the cutting process.

Various parameters of surface roughness i.e. Ra, Rz, Rmax measured by using Surface Roughness Tester – 211 Mitutoyo, Japan make, as shown in Fig. 4.4. Centre line average (C. L. A.) or Ra value is the arithmetic average roughness height. Average height difference between the five highest peaks and five lowest valleys within the traversing length are called peak to valley height.

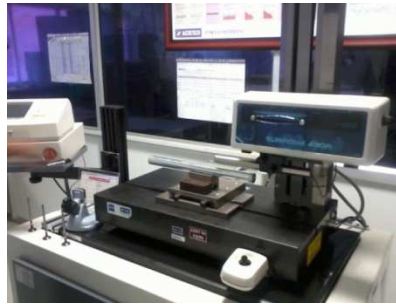


Figure 6: Surface Roughness Tester

Analysis Method

Robust design is an engineering methodology for obtaining product and process conditions, which are minimally sensitive to the various causes of variation to produce high-quality products with low development and manufacturing costs. Taguchi's parameter design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. Two major tools used in robust design are

- Signal to noise ratio, which measure quality with emphasis on variation, and
- Orthogonal arrays, which accommodate many design factors simultaneously.

When a critical quality characteristic deviates from the target value, it causes a loss. Continuously pursuing variability reduction from the target value in critical quality characteristics is the key to achieve high quality and reduce cost. The successful applications of Taguchi methods by both engineers and statisticians within British industry have led to the formation of UK Taguchi club. Taguchi's approach is totally based on statistical design of experiments and this can economically satisfy the needs of problem solving and products/process design optimization. By applying this technique one can significantly reduce the time required for experimental investigation, as it is effective in investigating the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence, which less.

Taguchi methods are statistical method developed by Dr. Genechi Taguchi, to improve the quality of manufactured goods, marketing and advertising. As a researcher in Electronic control laboratory in Japan, Genechi Taguchi carried out significant research with DOE techniques, in the late 1940's. Taguchi standardized version of DOE, popularly known as Taguchi method or Taguchi approach, was introduced in the USA in the early 1980's. By learning and applying this technique, engineers, scientist and researchers can significantly reduce the time required for experimental investigations.

Taguchi defines the quality of a product, in terms of the loss imparted by the product to the society from the time the product is shipped to the customer. Some of these losses are due to deviation of the product's functional characteristics

from its desired target value, and these are called losses due to functional variation. The uncontrollable factors which cause the functional characteristics of a product to deviate from their target values are called noise factors, which can be classified as external factors (e.g. temperatures and human errors), manufacturing imperfections (e.g. unit to unit variation in product parameters) and product deterioration. The overall aim of quality engineering is to make products that are robust with respect to all noise factors.

The most important stage in the design of an experiment lies in the selection of control factors. As many factors as possible should be included, so that it would be possible to identify non-significant variables at the earliest opportunity. Taguchi creates a standard orthogonal array to accommodate this requirement. Depending on the number of factors, interactions and levels needed, the choice is left to the user to select either the standard or column-merging method or idle-column method etc.

Taguchi used the signal-to-noise(S/N) ratio as the quality characteristic of choice. S/N ratio is used as a measurable value instead of standard deviation due to the fact that as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimized first and the mean brought to the target.

Taguchi has empirically found that the stage optimization procedure involving S/N ratios indeed gives the parameter level combination, where the standard deviation is minimum while keeping the mean on target. This implies that engineering systems behave in such a way that the manipulated production factors can be divided into three categories:

- Control factors, which affect process variability as measured by the S/N ratio.
- Signal factors, which do not influence the S/N ratio or process mean.
- Factors, which do not affect the S/N ratio or process mean.

Two of the applications in which the concept of S/N ratio is useful are the improvement of quality through variability reduction and the improvement of measurement. The S/N ratio characteristics can be divided into three categories when the characteristic is continuous:

- Smaller is the best: $S/N = -10\log_{10}(\text{mean of sum of squares of measured data})$
- Larger the better: $S/N = -10\log_{10}(\text{mean of sum of squares of reciprocal data})$
- Nominal is the best: $S/N = -10 \log_{10}(\text{square of mean /variance})$

For each type of the characteristics, with the above S/N ratio transformation, the higher the S/N ratio the better is the result

Fuzzy Logic

The conventional method to achieve lower surface roughness and cutting forces at different machining parameters is the “trial and error” approach. However, “trial and error” approach is very time consuming due to the large number of experiments. Hence, a reliable systematic approach to predict the surface roughness at different parameters condition is thus required to cover all the parameters range in a few numbers of experiments. Soft computing techniques are useful when exact mathematical information is not available and these differ from conventional computing in that it is tolerant of imprecision, uncertainty, partial truth, approximation, and met heuristics. Fuzzy logic is one of the soft computing

techniques that play a significant role in input output matrix relationship modeling. It is used when subjective knowledge and suggestion by the expert are significant in defining objective function and decision variables. Fuzzy logic is preferred to predicting surface roughness performance based on the input variables due to nonlinear condition in machining process. This paper applies the fuzzy logic to develop the rule model in order to predict the surface roughness of a machined surface in roller burnishing operation using single roller burnishing tool.

Following the literature above, for predicting of the surface roughness, this study has been conducted by spindle speed, feed rate and depth of cut as machining parameters. Fuzzy rule base method is proposed to predict surface roughness and hardness in burnishing process using tungsten carbide.

Fuzzy Logic Based Model to Predict Surface Roughness

The relationship between input parameters which are the lubrication pressure, spindle speed, feed rate and depth of cut with the output parameter which is surface roughness of a machined surface in glass milling operation were referred to construct the rules. Fuzzy linguistic variables and fuzzy expression for input and output parameters are shown in Table. For each input variable, four membership functions were used which are Low, Medium, High, and Very High. The output variable surface roughness also used four membership functions; Best, Good, Average and Bad.

Membership Functions for Input and Output Fuzzy Variables

In choosing the membership functions for fuzzification, the event and type of membership functions are mainly dependent upon the relevant event [45]. In this model, each input and output parameter has four membership functions. Gauss shape of membership function is employed to describe the fuzzy sets for input variables. In output variables fuzzy set, triangular shape of membership functions are used. Triangular membership function is generally used and possesses gradually increasing and decreasing characteristics with only one definite value [45]. The input variables have been partitioned according to the experiment parameter ranges.

RESULTS AND DISCUSSIONS

Roughness and Hardness Results

An L-27 orthogonal array is selected. For three factors and the columns to be selected are 1, 2 and 5. The factors selected and the levels chosen for the experimentation are shown in table 3.1. The results are analyzed using column effect method at levels 1, 2 and 3 are summed up and the difference at maximum and minimum values are obtained.

Table 3: L27 Orthogonal Array

S. no	Speed in rpm	Feed in rev / min	Depth of Cut in mm
1	1	1	1
2	1	1	2
3	1	1	3
4	2	1	1
5	2	1	2
6	2	1	3
7	3	1	1
8	3	1	2
9	3	1	3
10	1	2	1

Table 3: Contd.,			
11	1	2	2
12	1	2	3
13	2	2	1
14	2	2	2
15	2	2	3
16	3	2	1
17	3	2	2
18	3	2	3
19	1	3	1
20	1	3	2
21	1	3	3
22	2	3	1
23	2	3	2
24	2	3	3
25	3	3	1
26	3	3	2
27	3	3	3

Table 4: Surface Roughness and Hardness of Al 2014

S. no	Speed (rpm)	Feed (mm/min)	Depth of Cut (mm)	Aluminium 2014	
				Surface Roughness (μm)	Hardness (HRC)
1	100	0.2	0.5	0.717	52.2
2	100	0.2	1.0	0.706	52.8
3	100	0.2	1.5	0.713	54.5
4	125	0.2	0.5	0.668	52.3
5	125	0.2	1.0	0.660	56.8
6	125	0.2	1.5	0.621	54.5
7	150	0.2	0.5	0.584	52.4
8	150	0.2	1.0	0.520	51.8
9	150	0.2	1.5	0.551	54.0
10	100	0.4	0.5	0.541	41.2
11	100	0.4	1.0	0.538	52.5
12	100	0.4	1.5	0.631	56.9
13	125	0.4	0.5	0.533	53.0
14	125	0.4	1.0	0.592	52.5
15	125	0.4	1.5	0.620	56.1
16	150	0.4	0.5	0.596	54.1
17	150	0.4	1.0	0.590	52.6
18	150	0.4	1.5	0.586	52.5
19	100	0.6	0.5	0.601	56.0
20	100	0.6	1.0	0.631	53.2
21	100	0.6	1.5	0.602	52.3
22	125	0.6	0.5	0.639	52.5
23	125	0.6	1.0	0.600	54.0
24	125	0.6	1.5	0.646	52.0
25	150	0.6	0.5	0.634	53.1
26	150	0.6	1.0	0.526	55.0
27	150	0.6	1.5	0.528	51.4

Table 5: Surface Roughness and Hardness Al 6063

S. no	Speed (rpm)	Feed (mm/min)	Depth of Cut (mm)	Aluminium 6063	
				Surface Roughness (μm)	Hardness (HRC)
1	100	0.2	0.5	0.506	30.9
2	100	0.2	1.0	0.511	34.8
3	100	0.2	1.5	0.621	59.1
4	125	0.2	0.5	0.618	29.6
5	125	0.2	1.0	0.554	34.0
6	125	0.2	1.5	0.499	51.8
7	150	0.2	0.5	0.578	30.5
8	150	0.2	1.0	0.632	34.5
9	150	0.2	1.5	0.741	33.9
10	100	0.4	0.5	0.655	32.5
11	100	0.4	1.0	0.842	32.0
12	100	0.4	1.5	0.798	33.8
13	125	0.4	0.5	0.876	31.2
14	125	0.4	1.0	0.625	29.7
15	125	0.4	1.5	0.616	32.5
16	150	0.4	0.5	0.654	32.0
17	150	0.4	1.0	0.663	28.8
18	150	0.4	1.5	0.722	25.8
19	100	0.6	0.5	0.654	53.0
20	100	0.6	1.0	0.660	31.5
21	100	0.6	1.5	0.741	30.2
22	125	0.6	0.5	0.645	31.8
23	125	0.6	1.0	0.738	31.5
24	125	0.6	1.5	0.818	29.7
25	150	0.6	0.5	0.742	29.2
26	150	0.6	1.0	0.820	30.3
27	150	0.6	1.5	0.951	27.5

Table 6: S/N Ratio

S. no	Feed (mm/rev)	Cutting Speed (rpm)	Depth of Cut (mm)	Surface Roughness (μm)	Hardness HRC	S / N Ratio
1	100	0.2	0.5	0.717	52.2	-12.058
2	100	0.2	1.0	0.706	52.8	-13.454
3	100	0.2	1.5	0.713	54.5	-15.142
4	125	0.2	0.5	0.668	52.3	-12.856
5	125	0.2	1.0	0.66	56.8	-14.028
6	125	0.2	1.5	0.621	54.5	-14.982
7	150	0.2	0.5	0.584	52.4	-17.228
8	150	0.2	1.0	0.52	51.8	-16.924
9	150	0.2	1.5	0.551	54	-16.448
10	100	0.4	0.5	0.541	41.2	-13.846
11	100	0.4	1.0	0.538	52.5	-14.256
12	100	0.4	1.5	0.631	56.9	-16.284
13	125	0.4	0.5	0.533	53	-13.842
14	125	0.4	1.0	0.592	52.5	-14.026
15	125	0.4	1.5	0.62	56.1	-16.862
16	150	0.4	0.5	0.596	54.1	-16.942
17	150	0.4	1.0	0.59	52.6	-17.846
18	150	0.4	1.5	0.586	52.5	-13.882
19	100	0.6	0.5	0.601	56	-14.186
20	100	0.6	1.0	0.631	53.2	-14.948

Table 6: Contd.,						
21	100	0.6	1.5	0.602	52.3	-15.832
22	125	0.6	0.5	0.639	52.5	-13.962
23	125	0.6	1.0	0.6	54	-15.444
24	125	0.6	1.5	0.646	52	-16.188
25	150	0.6	0.5	0.634	53.1	-15.142
26	150	0.6	1.0	0.526	55	-16.992
27	150	0.6	1.5	0.528	51.4	-14.986

Effect of Depth of Cut on Surface Roughness and Hardness for Al 2014

The following graphs shows the relationship on surface roughness, hardness with burnishing speed, feed and depth of cut in aluminium 2014 and Effect of depth of cut on surface roughness for different burnishing speed at feed=0.2 mm / Rev, Number of Pass =1.

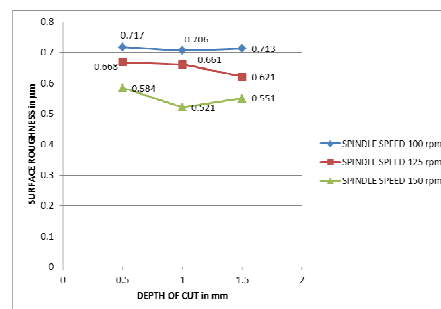


Figure 7: Effect of Depth of Cut on Surface Roughness

Figure7 shows that the effect of depth of cut on surface roughness for different burnishing speeds. It is apparent that burnishing process improves the surface roughness over depth of cut ranges from 1 mm to 1.5 mm when burnishing speed of 100 rpm and 150 rpm is given. This is due to when roller moves once again on the surface, more friction is developed between the tool and work piece. It can be observed that burnishing process decreases the surface roughness over depth of cut ranges from 1 to 1.5 mm when burnishing speed of 125 rpm is given. It seems that the plastic deformation will occur only when speed is given 125 rpm over the range of 1to1.5mm depth of cut.

Effect of Burnishing Speed on Surface Roughness

The following graph shows, the effect of burnishing speed on surface roughness for different burnishing feed at depth of cut=0.5mm, number of pass = 1.

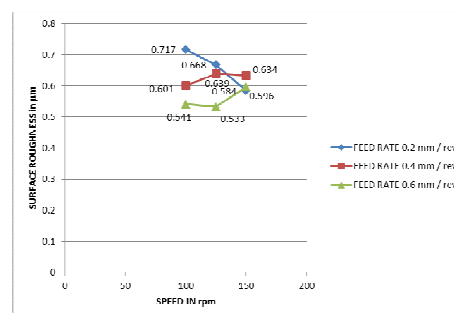


Figure 8: Effect of Burnishing Speed on Surface Roughness

Figure8 shows the effect of burnishing feed rate on the surface roughness for different burnishing feed. It can be seen that an increase in feed rate decreases the surface roughness of feed 0.2mm/ rev over the speed rate from 100 to 150

rpm. Also increase in feed rate increases the surface roughness of feed 0.2 and 0.6 mm/ rev over the speed rate from 100 to 150rpm. The effect of feed is very clear on the high feed rate, the high surface roughness. It is better to select low speeds because the deforming action of the burnishing tool is greater and metal flow is regular at low feed. However, as shown in figure 5 the effect of feed on surface roughness depends upon the burnishing feed. When carrying out the burnishing process at 0.4mm/rev feed, an increase in feed leads to decrease in surface roughness.

Effect of Depth of Cut on Surface Roughness and Hardness for Al 6063

The following graph shows the relationship on surface roughness, hardness with burnishing speed, feed and depth of cut in aluminium 6063 and Effect of depth of cut on surface roughness for different burnishing speed at feed=0.2 mm / rev, number of pass =1.

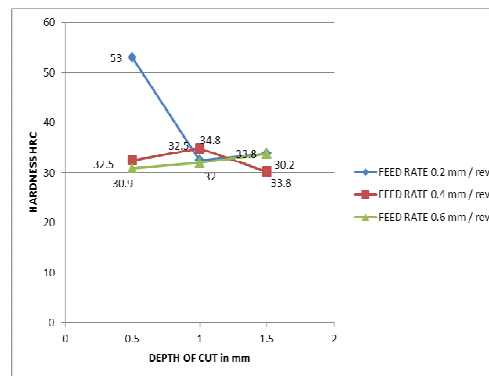


Figure 9: Effect of Depth of Cut on Hardness

Figure 9 shows that the effect of depth of cut on surface roughness for different burnishing speeds. It is apparent that burnishing process improves the surface roughness over depth of cut ranges from 1 mm to 1.5 mm when burnishing speed of 100 rpm and 150 rpm is given. This is due to when roller moves once again on the surface, more friction is developed between the tool and work piece. It can be observed that burnishing process decreases the surface roughness over depth of cut ranges from 1 to 1.5 mm when burnishing speed of 125 rpm is given. It seems that the plastic deformation will occur only when speed is given 125 rpm over the range of 1 to 1.5 mm depth of cut.

Analysis of Machining Parameters

Main Effects Plot for S/N Ratios

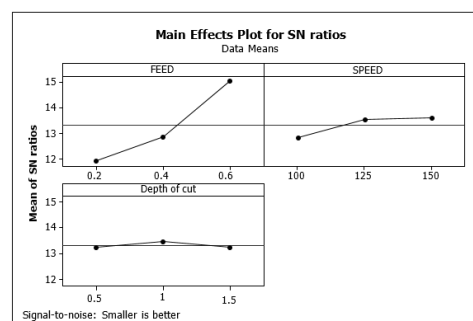


Figure 11: The Smaller the Better S/N Graph for Surface Roughness

The average S/N ratios for smaller the better for surface roughness are shown in figure11 The lowest burnishing speed 150 rpm and feed rate 0.2mm/rev for depth of cut 1 mm to be the best choice to get low surface roughness value.

The step is insignificant factor to get low surface roughness value. Therefore, the optimal combination to get low value of surface roughness is burnishing Speed and feed within the tested range.

Interaction Plot for SN Ratios for Third Number of Pass

The average S/N ratio for each level of the three factors is shown in fig. They are separate effects of each factor and commonly called main effects. The goal in the roller burnishing process is to minimize the surface roughness value of the burnished specimen by determining the optimal level of each factor. Study of the figure12 suggests that burnishing speed and interaction between feed rates is more significant. The optimal burnishing speed is 150 rpm and the optimal burnishing feed is 0.2mm/min.

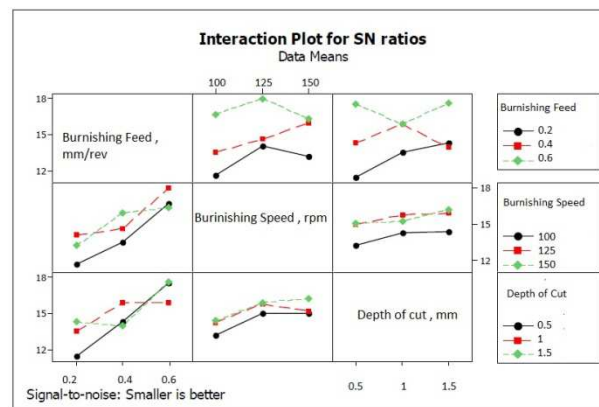


Figure 12: Plots of Control Factor Effects

FUZZY OPTIMIZATION

Table 7: Fuzzy Linguistic and Abbreviation of Variables

INPUTS		RANGE
PARAMETERS	LINGUISTIC VARIABLES	
A- No of passes	Low (L), Medium (M), High (H), Very High (VH)	0 To 3
B – Speed		100 To 150
C – Feed		0.2 To 0.6
D – Depth of cut		0.5 To 1.5
OUTPUTS		
Roughness	Best, Good, Average, Bad	0.2 To 0.717

Structure of Fuzzy Rules

A set of 27 rules have been constructed based on the actual experimental surface roughness of a machined surface in roller burnishing operation using single roller burnishing tool. Experimental results were simulated in the Mat lab software on the basis of Mandeni Fuzzy Logic which was as follow:

- IF (A is L) and (B is L) and (C is L) and (D is L) then (Roughness is high)
- IF (A is L) and (B is L) and (C is L) and (D is M) then (Roughness is high)
- IF (A is L) and (B is L) and (C is L) and (D is H) then (Roughness is high)
- IF (A is L) and (B is M) and (C is L) and (D is L) then (Roughness is Medium)

- IF (A is L) and (B is M) and (C is L) and (D is M) then (Roughness is Medium)
- IF (A is L) and (B is M) and (C is L) and (D is H) then (Roughness is Medium)
- IF (A is L) and (B is H) and (C is L) and (D is L) then (Roughness is Low)
- IF (A is L) and (B is H) and (C is L) and (D is M) then (Roughness is Low)
- IF (A is L) and (B is H) and (C is L) and (D is H) then (Roughness is Low)
- IF (A is M) and (B is L) and (C is M) and (D is L) then (Roughness is Low)
- IF (A is M) and (B is L) and (C is M) and (D is M) then (Roughness is Low)
- IF (A is M) and (B is L) and (C is M) and (D is H) then (Roughness is Medium)
- IF (A is M) and (B is M) and (C is M) and (D is L) then (Roughness is Low)
- IF (A is M) and (B is M) and (C is M) and (D is M) then (Roughness is Low)
- IF (A is M) and (B is M) and (C is M) and (D is H) then (Roughness is Medium)
- IF (A is M) and (B is H) and (C is M) and (D is L) then (Roughness is Low)
- IF (A is M) and (B is H) and (C is M) and (D is M) then (Roughness is Low)
- IF (A is M) and (B is H) and (C is M) and (D is H) then (Roughness is Low)
- IF (A is H) and (B is L) and (C is H) and (D is L) then (Roughness is Medium)
- IF (A is H) and (B is M) and (C is H) and (D is M) then (Roughness is Medium)
- IF (A is H) and (B is M) and (C is H) and (D is H) then (Roughness is Medium)
- IF (A is H) and (B is M) and (C is H) and (D is L) then (Roughness is Medium)
- IF (A is H) and (B is M) and (C is H) and (D is M) then (Roughness is Medium)
- IF (A is H) and (B is M) and (C is H) and (D is H) then (Roughness is Medium)
- IF (A is H) and (B is H) and (C is H) and (D is L) then (Roughness is Medium)
- IF (A is H) and (B is H) and (C is H) and (D is M) then (Roughness is Low)
- IF (A is H) and (B is H) and (C is H) and (D is H) then (Roughness is Low)

Procedure Followed in Fuzzy Logic

Step 1: Fuzzy Inputs

The first step is to take inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions.

Step 2: Apply Fuzzy Operators

Once the inputs have been fuzzified, we know the degree to which each part of the antecedent has been satisfied

for each rule. If a given rule has more than one part, the fuzzy logical operators are applied to evaluate the composite firing strength of the rule.

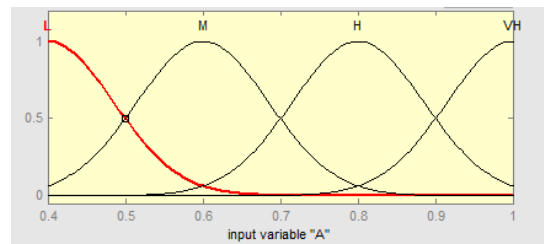


Figure 13: Membership Function for Input Variable A

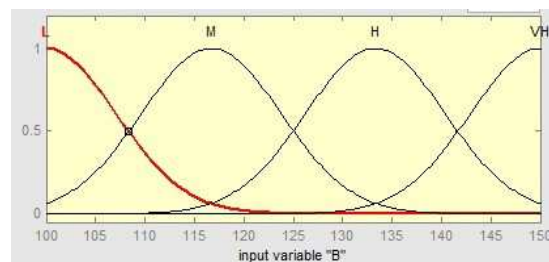


Figure 14: Membership Function for Input Variable B

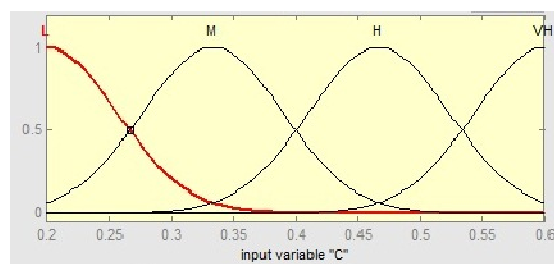


Figure 15: Membership Function for Input Variable C

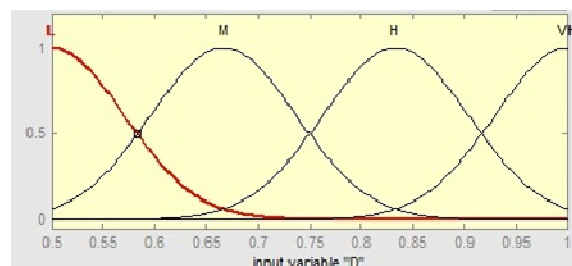


Figure 16: Screenshot of Fuzzy Logic for Input Variable D

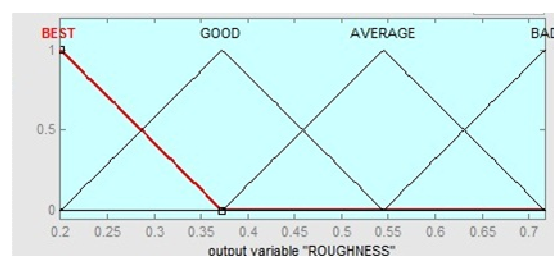


Figure 17: Membership Function for Output Variable

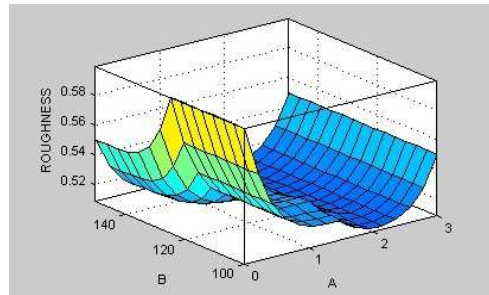


Figure 18: Surface Roughness's in Relation to Change of Depth of Cut and No of Passes

Figure 18 are to show the relation between input parameters change and surface roughness of a machined surface in burnishing process predicted by fuzzy based model. The surface roughness significantly increased with the increasing of depth of cut.

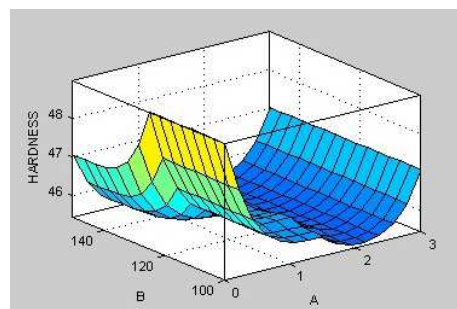


Figure 19: Hardness in Relation to Change of Depth of Cut and No of Passes

Figure 19 are to show the relation between input parameters change and hardness of a machined surface in burnishing process predicted by fuzzy based model. The hardness significantly increased with the increasing of depth of cut.

Step 3: Apply the Implication Method

The implication method is defined as the shaping of the output membership functions on the basis of the firing strength of the rule. The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Two commonly used methods of implication are the minimum and the product.

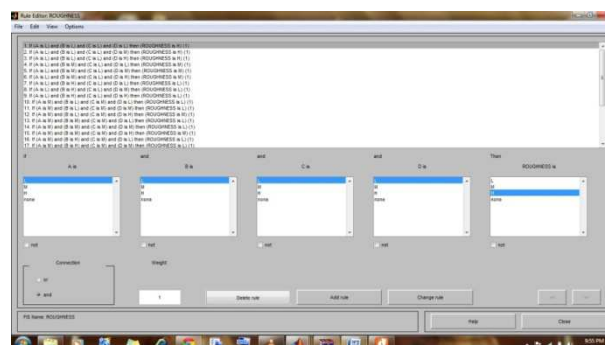


Figure 30: Rule Editor

Step 4: Aggregate all Outputs

Aggregation is a process whereby the outputs of each rule are unified. Aggregation occurs only once for each

output variable. The input to the aggregation process is the truncated output fuzzy sets returned by the implication process for each rule. The output of the aggregation process is the combined output fuzzy set.

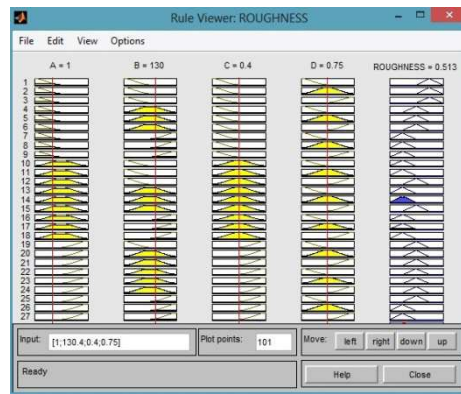


Figure 31: Surface Roughness Rule Viewer

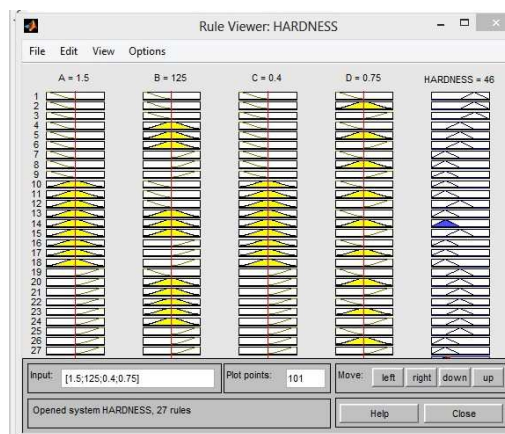


Figure 32: Screenshot for Hardness Rule Viewer

Step 5: Defuzzify

The input for the defuzzification process is a fuzzy set (the aggregated output fuzzy set), and the output of the defuzzification process is a crisp value obtained by using some defuzzification method such as the centroid, height, or maximum.

CONCLUSIONS

The roller-burnishing surface finishing process of Aluminum 2014 and Aluminum 6063 is done successfully on a lathe center in this paper. The optimal roller burnishing parameters are determined by conducting the process of the Taguchi's L27 orthogonal array; signal-to-noise (S/N) ratio, from the result of analysis in roller burnishing using conceptual S/N ratio approach, the following can be concluded from the paper

Comparing both the material it was observed that the aluminum 2014 gives better results than aluminum 6063.

According to the Experimental Value

- The optimal roller burnishing parameters for better surface roughness 0.520 in Aluminum 2014 are the combination of the burnishing speed 150 rpm, the burnishing feed 0.2 mm / rev and the depth of cut of 1mm

- The optimal roller burnishing parameters for better hardness 56.9 in Aluminum 2014 are the combination of the burnishing speed 100 rpm, the burnishing feed 0.6 mm / rev and the depth of cut of 0.5mm

According to the Fuzzy Logic

- The optimal roller burnishing parameters for best surface roughness 0.513 μ m in Aluminum 2014 are the combination of the burnishing speed 130rpm, the burnishing feed 0.4 mm / rev and the depth of cut of 0.75mm.
- The optimal roller burnishing parameters for best hardness 46 Aluminum 2014 is the combination of the burnishing speed 125rpm, the burnishing feed 0.4 mm / rev and the depth of cut of 0.75mm.

REFERENCES

1. N.S.M. El-Tayeb., et.al K.O. Low, P.V. Brevern. *Influence of roller burnishing contact width and burnishing orientation on surface quality and tribological behavior of Aluminium 6061* Faculty of Engineering and Technology, Multimedia University, 75450 Melaka, Malaysia
2. *Optimization of roller burnishing process for aluminium using taguchi technique*, sundararajan p.n. (2009), SRM University, Chennai.
3. Luca L, Neagu-Ventzel S, Marinescu I. (2005) *Effects of working parameters on surface finish in ball-burnishing of hardened steels*. *Precision Eng.*; 29:253–256.
4. Hassan A.M. (1997) *The effects of ball- and roller-burnishing on the surface roughness and hardness of some non-ferrous metals*. *J Mater Process Technol*; 72:385–391.
5. M. Matheswaran & P. Suresh, *Study of EDM Process Parameters of Surface Roughness in Titanium Using Taguchi Method*, *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Volume 4, Issue 2, March - April 2014, pp. 63-68
6. Yeldose BC, Ramamoorthy B. (2008) *an investigation into the high performance of Tin coated rollers in burnishing process*. *J Mater Process Technol*; 207:350–355.
7. Luo HY, Liu J. (2005) *Investigations of the burnishing process with PCD tool on non-ferrous metals*. *Int J Adv. Manuf Technol*; 25:454–459.
8. Nemat M, Lyons AC. (2000) *An investigation on the surface topography of ball burnished mild steel and aluminum*. *Int J AdvManufTechnol*; 16:469–473.
9. Bonzid W, Soumarer OT, SaiK.An (2004) *investigation of surface roughness of burnished AISI 1042 steel*. *Int J Manuf Technol*; 24:120–125.
10. Luo HY, Liu J. (2006) *Investigations of the effect of burnishing force during the burnishing process with a cylindrical surface tool*. *J EngManuf*; 220:893–904.
11. Adal MH, Ayman MM. (2000) *the effects of initial burnishing parameters on nonferrous components*. *J Mater Process Technol*; 102:115–121.
12. Vishal Francis & Ashutosh Dubey, *Application of Taguchi and Response Surface Methodologies for Surface Roughness in Face Milling Operation*, *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Volume 3, Issue 2, May - June 2013, pp. 213-220

13. Esme U, Sagbas A, Kahraman F, Kulekci MK. (2008) Use of artificial neural networks in ball burnishing process for the prediction of surface roughness of AA 7075 aluminum alloy. *Mater Tehnol*; 42:215–219.
14. Korzynski M. (2007) Modeling and experimental validation of the force-surface roughness relation for smoothing burnishing with a spherical tool. *Int J Mach Tools Manuf*; 47:1956–1964.
15. Seemikeri CY, Brahmanekar PK, Mahagaonkar SB. (2008) Investigation on surface integrity of AISI 1045 using LPB tool. *TribolInt*; 41:724–734.
16. Hassan IS, Al-Jalil HF, Ebied AA. (1998) Burnishing force and number of passes for the optimum surface finish of brass components. *J Mater Process Technol*; 83:176–179.
17. El-Tayeb NSM, Low KO, Brevern PV. (2009) On the surface and tribological characteristics of burnished cylindrical Al-6061. *TribolInt*; 42:320–326.
18. Rao DS, Hebbar HS, Komaraiah M, Kempaiah UN. (2008) Investigations on the effect of ball burnishing parameters on surface hardness and wear resistance of HSLA dual-phase steels. *Mater Manuf Process*; 23:295–302.
19. Loh NH, Tam SC, Miyazawa S. (1989) A study of the effects of ball burnishing parameters on surface roughness using factorial design. *J Mech Work Technol*; 18:53–61.
20. El-Khabeery MM, El-Axir MH. (2001) Experimental techniques for studying the effects of milling roller burnishing parameters on surface integrity. *Int J Machine Tools Manuf*; 41:175–179.
21. El-Taweel TA, El-Axir MH (2009) Analysis and optimization of the ball burnishing process through the Taguchi technique. *Int J Adv. Manuf Technol*; 41:301–310.
22. El-Axir MH, Othman OM, AbodienaAM. (2008) Study on the inner surface finishing of aluminum alloy 2014 by ball burnishing process. *J Mater Process Technol*; 202:435–442.
23. El-Taweel TA, Ebied SJ (2009) Effect of hybrid electromechanical smoothing-roller burnishing process parameters on roundness error and micro-hardness. *Int J AdvManufTechnol*; 42:643–655.
24. Yan BH, Wang CC, Chow HM, Lin YC. (2000) Feasibility study of rotary electrical discharge machining with ball burnishing for Al₂O₃/6061 Al composite. *Int J Machine Tools Manuf*; 40:1403–1421.
25. Shiou FJ, Hsu CC. (2008) Surface finishing of hardened and tempered stainless tool steel using sequential ball grinding, ball burnishing and ball polishing processes on a machining centre. *J Mater Process Technol*; 205:249–258.
26. Shiou FJ, Cheng CH. (2008) Ultra-precision surface finish of NAK80 mould tool steel using sequential ball burnishing and ball polishing processes. *J Mater Process Technol*; 201:554–559.
27. Shiou FJ, Chen CH. (2003) Determination of optimal ball-burnishing parameters for plastic injection moulding steel. *Int J AdvManufTechnol*; 3:177–185.
28. Basak H, Goktas HH. (2009) Burnishing process on Al-alloy and optimization of surface roughness and surface hardness by fuzzy logic. *Mater Des*; 30:1275–1281.
29. M. Fattouh, M.M. El-Khabeery, (1989) Residual stress distribution in burnishing solution treated and aged 7075 aluminium alloy, *International Journal Machine Tool Manufacture* 29/1 153-160.
30. F. Klocke, J. Liermann, (1998) Roller burnishing of hard turned surface, *International Journal of Machine Tool Manufacture* 38/5-6 419-423.

31. A.M. Hassan and A.M.Maqableh, (2000) the effect of initial burnishing parameters on non-ferrous components, *Journal of Materials Processing Technology* 102 115-121.
32. M. N.mat, A.C. Lyons, (2001) an investigation of the surface topography of ball burnished mild steel and aluminium, *International Journal of Advanced Manufacturing Technology* 16 469-473.
33. S. Thamizhmanii, et al B. Saparudin, S. Hasan, (2007) A study of multi-roller burnishing on non-ferrous metals, *Journal of Achievements in Mechanical and Manufacturing Engineering* 22/2 95-98.
34. E.M. Rubio, et al A.M. Camacho, J.M. Snchez-Sola, M. Marcos, (2006) Chip arrangement in the dry cutting of aluminium alloys, *Journal of Achievements in Materials and Manufacturing Engineering* 19 11-18.
35. Shneider, Yu. G.,(1967), "Characteristics of burnished components", *Mechanical Tooling*, 38, pp.19-22.
36. Shaw, M. C., (2009), "Metal Cutting Principles", 3 rd ed., Oxford and I B H Publication Company, New Delhi.
37. Murthy R. L., and Kotiveerachary B.,(1981), "Burnishing of Metallic Surfaces – A Review", *Precision Engineering J.*, 3, pp.172 – 179.
38. Loh N. H., Tam S. C. and Miyazawa S., (1991), "Investigations on the surface roughness produced by Ball Burnishing", *Int. J. Machine Tools Manufacture*, 31, pp.75 – 81.
39. Hassan A.M., (1997), "The effects of ball and roller burnishing on the surface roughness and hardness of some non-ferrous metals", *J. Materials Processing Technology*, 72, pp.385 – 391.
40. Thamizhmanii S, et.al. Bin Omar B., Saparudin S. and Hassan S., (2008), "Surface roughness investigation and hardness by burnishing on titanium alloy", *J.Achievements in Materials and Manufacturing Engineering*, 28, pp.139 – 142.
41. C.H. Che-Haron, A. Jawaid, (2005) The effect of machining on surface integrity of titanium alloy Ti-6% Al-4%V, *Journal of Materials Processing Technology* 166 188-192. [2]G. Byne, J. Barry, P. Young, Surface integrity of AISi9 machined with PCD cutting tools, *Annals CIRP* 46 (1997) 489-492.
42. A.M. Arao, M. Wisc, D. Aspinwall, (1998) Tool life and work piece surface integrity evaluations when machining hardened AISI H13 and AISI 52100 steels with conventional ceramic and PCBN tool materials, *SME Technical Paper No. MR 95-159*.
43. Finite Element Modeling of Roller Burnishing Process, Y.C. Yen, et al P. Sartkulvanich, T. Altan (1) Engineering Research Centre for Net Shape Manufacturing (ERC/NSM), The Ohio State University, Columbus, Ohio, USA
44. Text book of engineering metrology by R.K.Jain, (2002) eighteenth edition
45. A.M. Hassan and A.M.Maqableh, (2000) the effect of initial burnishing parameters on non-ferrous components, *Journal of Materials Processing Technology* 102 115-121.
46. Hassan A.M., (1997), "The effects of ball and roller burnishing on the surface roughness and hardness of some non-ferrous metals", *J. Materials Processing Technology*, 72, pp.385 – 391.
47. Ahmed A. D. Sarhan, M. Sayuti, and M. Hamdi.,(2012) A Fuzzy Logic Based Model to Predict Surface Roughness of A Machined Surface in Glass Milling Operation Using CBN Grinding Tool. *World Academy of Science, Engineering and Technology*

